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Worldwide trends in blood pressure from 1975 to 2015: a pooled analysis of 1479 population-based measurement studies with 19·1 million participants

NCD Risk Factor Collaboration (NCD-RisC)*



Summary

Background Raised blood pressure is an important risk factor for cardiovascular diseases and chronic kidney disease. We estimated worldwide trends in mean systolic and mean diastolic blood pressure, and the prevalence of, and number of people with, raised blood pressure, defined as systolic blood pressure of 140 mm Hg or higher or diastolic blood pressure of 90 mm Hg or higher.

Methods For this analysis, we pooled national, subnational, or community population-based studies that had measured blood pressure in adults aged 18 years and older. We used a Bayesian hierarchical model to estimate trends from 1975 to 2015 in mean systolic and mean diastolic blood pressure, and the prevalence of raised blood pressure for 200 countries. We calculated the contributions of changes in prevalence versus population growth and ageing to the increase in the number of adults with raised blood pressure.

Findings We pooled 1479 studies that had measured the blood pressures of 19·1 million adults. Global age-standardised mean systolic blood pressure in 2015 was 127·0 mm Hg (95% credible interval 125·7–128·3) in men and 122·3 mm Hg (121·0–123·6) in women; age-standardised mean diastolic blood pressure was 78·7 mm Hg (77·9–79·5) for men and 76·7 mm Hg (75·9–77·6) for women. Global age-standardised prevalence of raised blood pressure was 24·1% (21·4–27·1) in men and 20·1% (17·8–22·5) in women in 2015. Mean systolic and mean diastolic blood pressure decreased substantially from 1975 to 2015 in high-income western and Asia Pacific countries, moving these countries from having some of the highest worldwide blood pressure in 1975 to the lowest in 2015. Mean blood pressure also decreased in women in central and eastern Europe, Latin America and the Caribbean, and, more recently, central Asia, Middle East, and north Africa, but the estimated trends in these super-regions had larger uncertainty than in high-income super-regions. By contrast, mean blood pressure might have increased in east and southeast Asia, south Asia, Oceania, and sub-Saharan Africa. In 2015, central and eastern Europe, sub-Saharan Africa, and south Asia had the highest blood pressure levels. Prevalence of raised blood pressure decreased in high-income and some middle-income countries; it remained unchanged elsewhere. The number of adults with raised blood pressure increased from 594 million in 1975 to 1·13 billion in 2015, with the increase largely in low-income and middle-income countries. The global increase in the number of adults with raised blood pressure is a net effect of increase due to population growth and ageing, and decrease due to declining age-specific prevalence.

Interpretation During the past four decades, the highest worldwide blood pressure levels have shifted from high-income countries to low-income countries in south Asia and sub-Saharan Africa due to opposite trends, while blood pressure has been persistently high in central and eastern Europe.

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Introduction

Raised blood pressure is the leading global risk factor for cardiovascular diseases and chronic kidney disease.¹ One of the global non-communicable disease (NCD) targets adopted by the World Health Assembly in 2013 is to lower the prevalence of raised blood pressure, defined as systolic blood pressure of 140 mm Hg or higher or diastolic blood pressure of 90 mm Hg or higher, by 25% compared with its 2010 level by 2025.² Consistent global information is needed to understand how countries compare on blood pressure levels and trends, and where interventions to curtail the rise in blood pressure are most needed.

The prevalence of raised blood pressure measures the number of high-risk people irrespective of treatment status, and is the indicator used in the global NCD target. However, blood pressure has a log-linear association with cardiovascular diseases and chronic kidney disease that continues well below the threshold for raised blood pressure, and treatment provides similar proportional risk reductions irrespective of pretreatment blood pressure.^{3,4} Trends in mean population blood pressure measure how blood pressure distribution has shifted over time.

We pooled population-based data to estimate national, regional, and global trends from 1975 to 2015 in mean

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*NCD Risk Factor Collaboration members are listed at the end of the paper

Correspondence to:
Prof Majid Ezzati,
Imperial College London,
London W2 1PG, UK
majid.ezzati@imperial.ac.uk

Research in context

Evidence before this study

We searched MEDLINE (via PubMed) for articles published in English, Spanish, Portuguese, Chinese, Italian, French, or Farsi between Jan 1, 1950, and Feb 19, 2014, using the search terms ("blood pressure"[Mesh:NoExp] OR "hypertension"[Mesh:NoExp]) AND ("Humans"[Mesh]). We screened articles according to the inclusion and exclusion criteria described in the appendix.

Some studies, including the MONICA Project, have reported on blood pressure change or trends in one or more countries. Two previous global analyses, done more than a decade ago, pooled data from different countries and reported mean systolic blood pressure or prevalence of hypertension in the year 2000 for the world and its major regions. A more recent analysis published in 2016 pooled 135 studies to estimate global and regional hypertension prevalence in 2000 and 2010, but did not report changes in mean blood pressure, which reflect shifts in the population distribution of blood pressure. None of these studies provided consistent estimates for all countries or accounted for the fact that the data used were collected in different years. The only analysis of trends at the country level reported mean systolic blood pressure from 1980 to 2008 but did not report mean diastolic blood pressure or prevalence of raised blood pressure, which is of clinical relevance and needed for monitoring progress towards the global target.

Added value of this study

This study provides the most complete picture of trends in adult blood pressure for all countries in the world with the longest observation period of any global blood pressure study to our knowledge, and includes trends in mean diastolic blood pressure and prevalence of raised blood pressure, which were not included in previous studies and are of clinical, public health, and health systems significance. We also estimated trends in the number of adults with raised blood pressure, and how much these trends are driven by changes in prevalence versus population size and age structure.

Implications of all the available evidence

During the past four decades, the highest levels of blood pressure worldwide have shifted from high-income countries to low-income and middle-income countries in south Asia and sub-Saharan Africa, while blood pressure has been persistently high in central and eastern Europe. The global target of reducing raised blood pressure prevalence by 25% by 2025 is unlikely to be achieved in these regions. The number of people with raised blood pressure has risen worldwide, with the increase happening mainly in low-income and middle-income countries. Population-based interventions throughout the life-course and pharmacological treatment for people with high absolute risk or people with substantially raised blood pressure should be a part of any effort to address the global burden of non-communicable diseases, especially in the poorest countries.

systolic and mean diastolic blood pressure, and in the prevalence of raised blood pressure, for adults aged 18 years and older in 200 countries and territories. We also estimated trends in the number of adults with raised blood pressure, and calculated how much these trends are attributable to changes in prevalence versus changes in population size and age structure.

Methods

Study design and data sources

For this pooled analysis, we included data collected from samples of a national, subnational (ie, covering one or more subnational regions), or community (one or a small number of communities) population in which participants' blood pressure had been measured. Our methods for identifying and accessing data sources are described in the appendix (pp 2–6). When a study measured blood pressure more than once in participants (1053 [86%] of 1220 studies for which information about number of measurements was available), we discarded the first measurement, and used the average of the remainder.

292 (20%) of the 1479 data sources we analysed (2298 [16%] of 14 391 age-sex-study-specific data points) that were from a previous global pooling⁵ or extracted from publications did not have data on one or more of

our primary outcomes. We used regressions to convert available data in these sources to the missing primary outcomes because the various blood pressure outcomes are correlated.⁶ Details of conversion (or so-called cross-walking) regressions and their coefficients are presented in the appendix (pp 7, 8, 44–152).

Statistical analysis

The statistical model used to estimate means and prevalence by country, year, and age is described in detail in a statistical paper and related substantive papers.^{5,7,8} In summary, we organised countries into 21 regions, mainly on the basis of geography and national income, which we further aggregated into nine "super-regions" (appendix pp 14, 15). The model had a hierarchical structure in which estimates for each country and year were informed by its own data, if available, and by data from other years in the same country and from other countries, especially countries in the same region with data for similar time periods. The hierarchical structure shares information to a greater extent when data are non-existent or weakly informative (eg, have a small sample size or are not national), and to a lesser extent for data-rich countries and regions.

The model incorporated non-linear time trends and age patterns. It allowed the age association of blood pressure

See Online for appendix

to vary across populations, and the rise in means and prevalence over age to be steeper where blood pressure is higher.^{9,10} The model accounted for the possibility that blood pressure in subnational and community studies might systematically differ from nationally representative ones, and might also have larger variation than in national studies; the model also accounted for rural–urban differences in blood pressure, and used it to adjust rural-only and urban-only studies. The statistical model included covariates that help predict blood pressure, including mean number of years of education, proportion of national population living in urban areas, and a summary measure of availability of different food types for human consumption (appendix pp 9, 10).

We fitted the statistical model with the Markov chain Monte Carlo algorithm, and obtained 5000 post-burn-in samples from the posterior distribution of model parameters, which were in turn used to obtain the posterior distributions of primary outcomes. The reported credible intervals (CrI) represent the 2·5th to 97·5th percentiles of the posterior distributions. Each primary outcome was analysed separately, and all analyses were done separately by sex to allow blood pressure, its trends, and age associations to differ among outcomes and between men and women.

We calculated mean change in mean blood pressure and the prevalence of raised blood pressure across the 41 years of analysis (reported as change per decade). We also report the posterior probability (PP) that an estimated trend represents a true increase or decrease. We generated age-standardised estimates using the WHO standard population,¹¹ by taking weighted means of age–sex-specific estimates, with use of age weights from the standard population. We tested how our statistical model predicted mean blood pressure and the prevalence of raised blood pressure when a country-year did not have data (appendix pp 11–13), which showed that the model performed well in its predictive validity.

We calculated the contribution of population growth and ageing to the change in the number of adults with raised blood pressure by fixing age-specific prevalence at its 1975 levels while allowing age-specific population to change as it did. We calculated the contribution of change in prevalence by fixing age-specific population at its 1975 level while allowing age-specific prevalence to change as it did. The interaction between the two contributions is the residual change in the number of adults with raised blood pressure after accounting for the two forementioned components.

Role of funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. Country and Regional Data Group members and BZ had full access to the data in the study. The corresponding author had final responsibility for the decision to submit for publication.

Results

We included 1479 population-based measurement surveys and studies, with 19·1 million participants aged 18 years and older for whom blood pressure was measured. We had at least one data source for 174 (87%) of the 200 countries we made estimates for, covering 97·5% of the world's population in 2015 (appendix pp 193, 194), and at least two data sources for 122 (61%) countries. Of these 1479 sources, 517 (35%) were from national samples, 249 (17%) covered one or more subnational regions, and the remaining 713 (48%) were from one or a small number of communities. Regionally, data availability ranged from 0·83 data sources per country in central Africa to 37 sources per country in high-income Asia Pacific. 543 (37%) data sources were from years before 1995 and another 936 (63%) were from 1995 and later.

Globally, age-standardised adult mean systolic blood pressure remained virtually unchanged from 1975 to 2015 in men (126·6 mm Hg [95% CrI 124·0 to 129·3] in 1975 and 127·0 mm Hg [125·7 to 128·3] in 2015; an increase of 0·07 mm Hg per decade [−0·59 to 0·74]; PP of being a true increasing trend is 0·5808) and decreased slightly in women (123·9 mm Hg [121·3 to 126·6] in 1975 and 122·3 mm Hg [121·0 to 123·6] in 2015; a decrease of 0·47 mm Hg per decade [−0·20 to 1·15]; PP=0·9210; figure 1). Trends in age-standardised mean diastolic blood pressure, which was 78·7 mm Hg (77·9 to 79·5) for men and 76·7 mm Hg (75·9 to 77·6) for women in 2015, were similar (figure 2).

Mean systolic and mean diastolic blood pressure decreased substantially during these four decades in high-income western and high-income Asia Pacific super-regions, moving these two super-regions from being among those with the highest blood pressure in 1975 to the lowest in 2015 (figures 1, 2). The largest decrease in mean systolic blood pressure, which occurred in high-income Asia Pacific, was 3·2 mm Hg per decade (95% CrI 2·4–3·9) for women and 2·4 mm Hg per decade (1·6–3·1) for men (PP>0·9999). The largest decrease in mean diastolic blood pressure, which was in the high-income western super-region, was 1·8 mm Hg per decade (1·4–2·3) for women and 1·5 mm Hg per decade (1·0–1·9) for men (PP>0·9999). Mean systolic blood pressure also seems to have decreased in women in central and eastern Europe, Latin America and the Caribbean, and, more recently, central Asia, Middle East, and north Africa, but the estimated trends in these super-regions had larger uncertainty than those in high-income super-regions; mean diastolic blood pressure showed a similar, but less pronounced, decrease in these super-regions (figures 1, 2). Little or no change in mean systolic or mean diastolic blood pressure occurred in men in these super-regions.

By contrast with these decreases, mean systolic blood pressure might have increased in men and women in east and southeast Asia, south Asia, Oceania, and sub-Saharan Africa, with a similar trend in mean diastolic

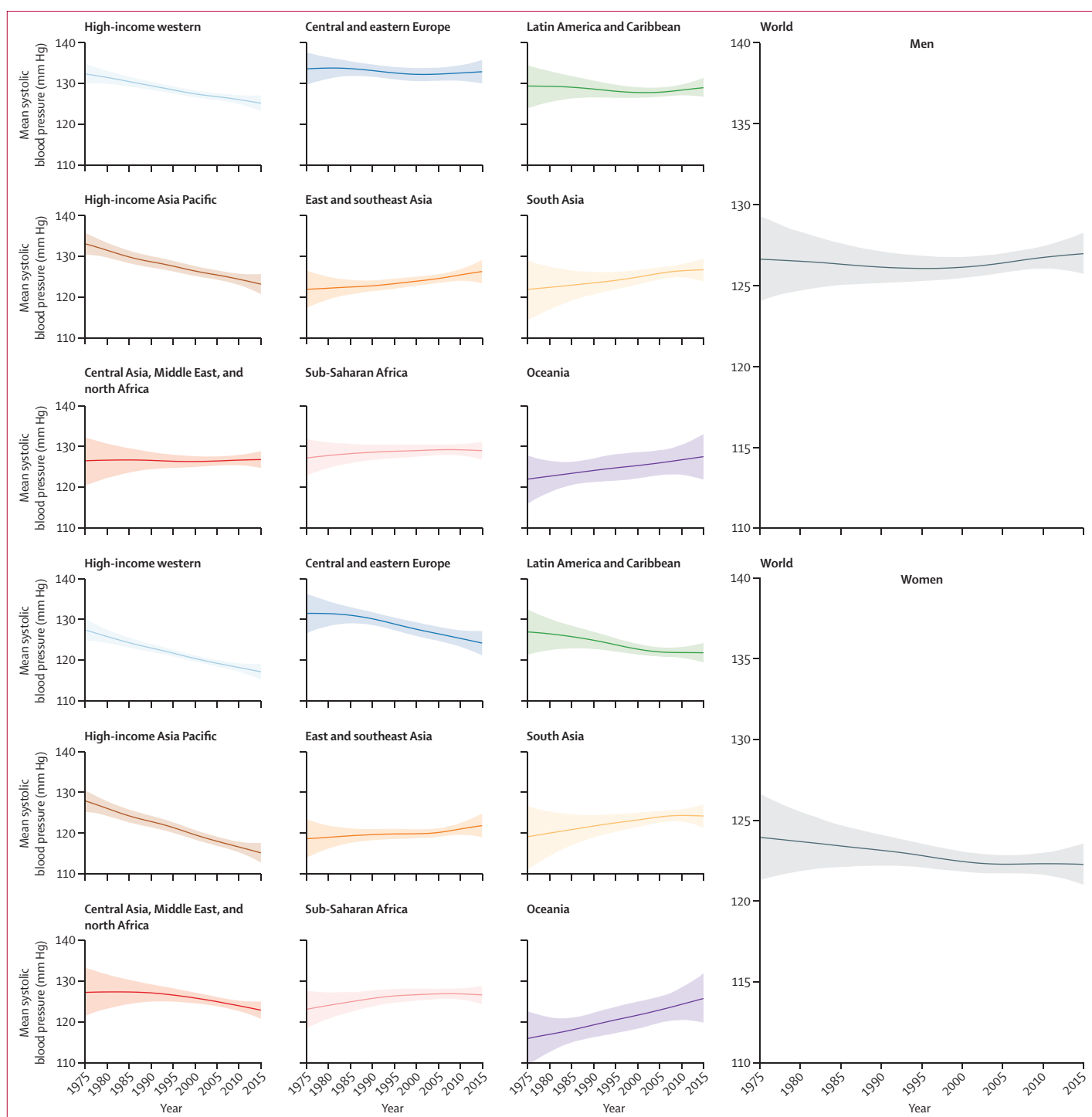


Figure 1: Trends in age-standardised mean systolic blood pressure by sex and super-region in people aged 18 years and older

The lines show the posterior mean estimates and the shaded areas show the 95% CrI. See appendix (pp 199–266) for trends by country.

blood pressure (figures 1,2). Central and eastern Europe, sub-Saharan Africa, and south Asia had the highest mean blood pressures in 2015.

Age-standardised prevalence of raised blood pressure decreased globally from 1975 to 2015, from

29·5% (95% CrI 24·2–35·0) to 24·1% (21·4–27·1) in men (PP=0·9482) and from 26·1% (21·7–31·1) to 20·1% (17·8–22·5) in women (PP=0·9884). The largest decrease was seen in high-income super-regions, followed by Latin America and the Caribbean, central

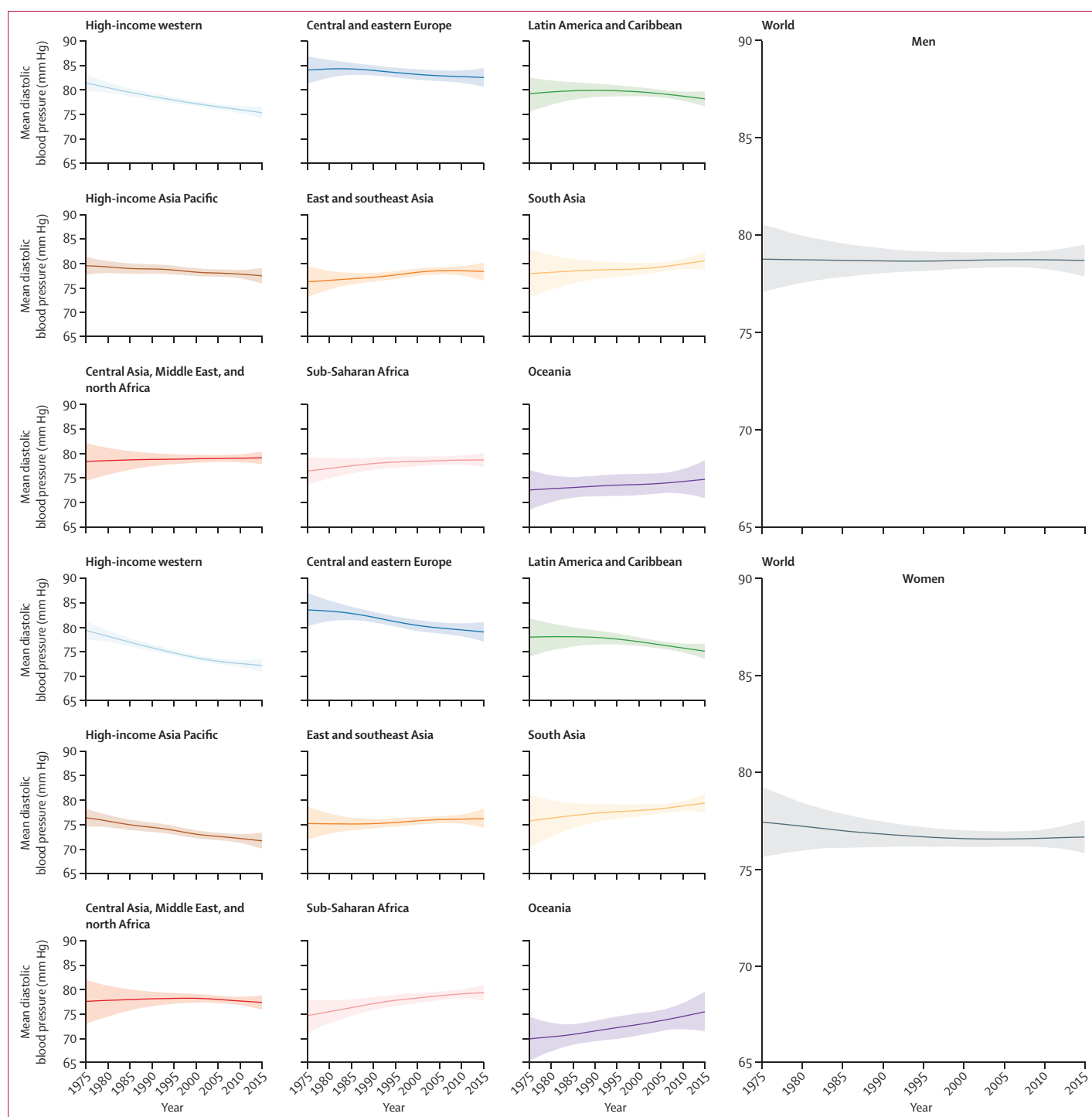


Figure 2: Trends in age-standardised mean diastolic blood pressure by sex and super-region in people aged 18 years and older

The lines show the posterior mean estimates and the shaded areas show the 95% CrI. See appendix (pp 199–266) for trends by country.

and eastern Europe, and central Asia, Middle East, and north Africa (figure 3). Elsewhere, age-standardised prevalence of raised blood pressure remained unchanged. Crude prevalence decreased more slowly than age-standardised prevalence, especially

where there has been substantial ageing (eg, in high-income super-regions and Latin America and the Caribbean).

South Korea and Canada had the lowest age-standardised mean systolic blood pressure in 2015 for

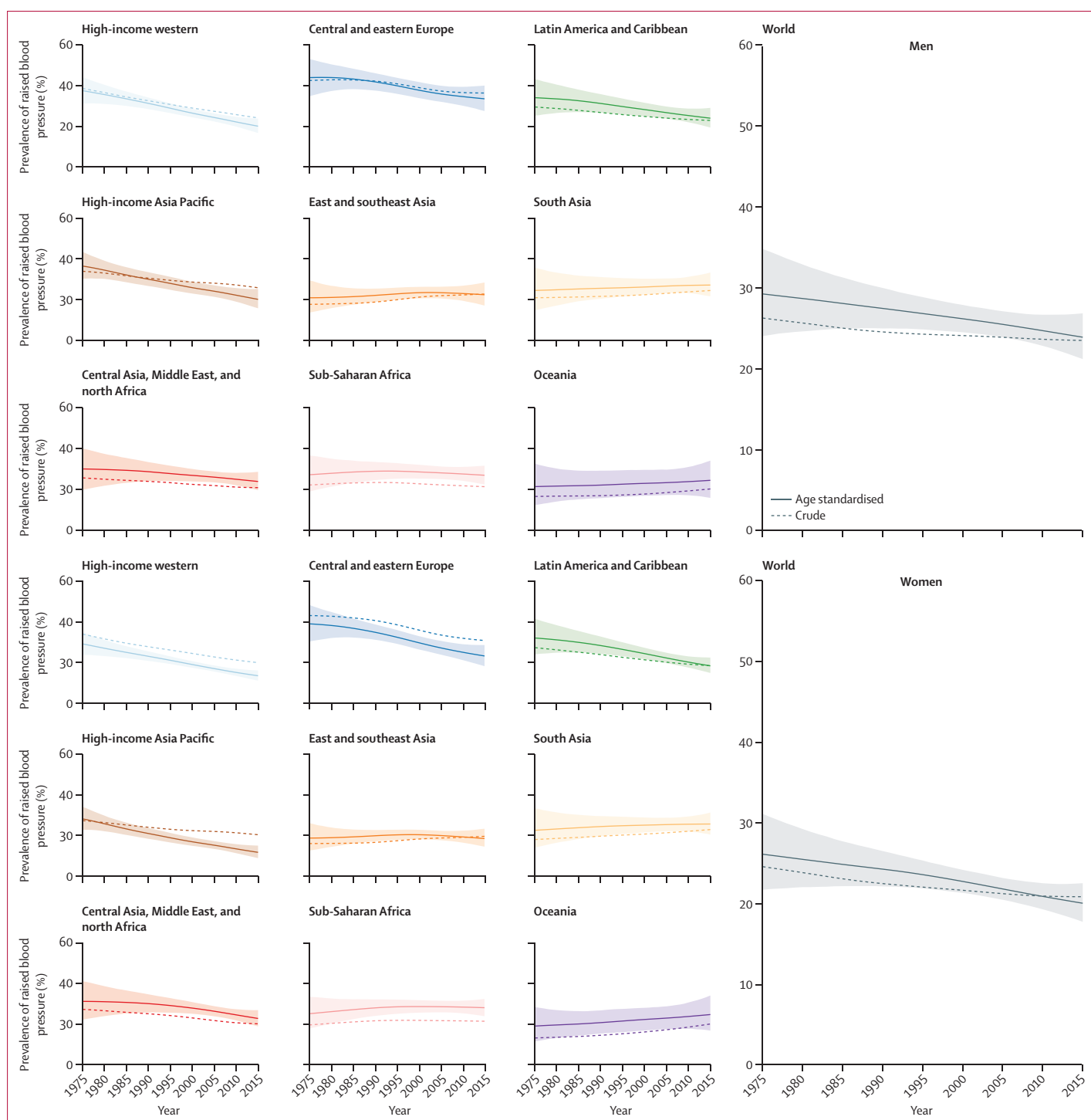


Figure 3: Trends in age-standardised and crude prevalence of raised blood pressure by sex and super-region in people aged 18 years and older

The lines show the posterior mean estimates and the shaded area shows the 95% CrI for age-standardised prevalence. See appendix (pp 267–334) for trends by country.

both men (117–118 mm Hg) and women (about 111 mm Hg; figure 4). The highest mean systolic blood pressures in men were seen in some countries in central and eastern Europe (eg, Slovenia, Lithuania, and Croatia), Oceania, central Asia, and sub-Saharan Africa, with

age-standardised mean systolic blood pressure reaching 137.5 mm Hg (95% CrI 131.2–143.8) in Slovenia. Women in a few countries in sub-Saharan Africa (eg, Niger, Guinea, Malawi, and Mozambique) had the highest levels of mean systolic blood pressure, surpassing

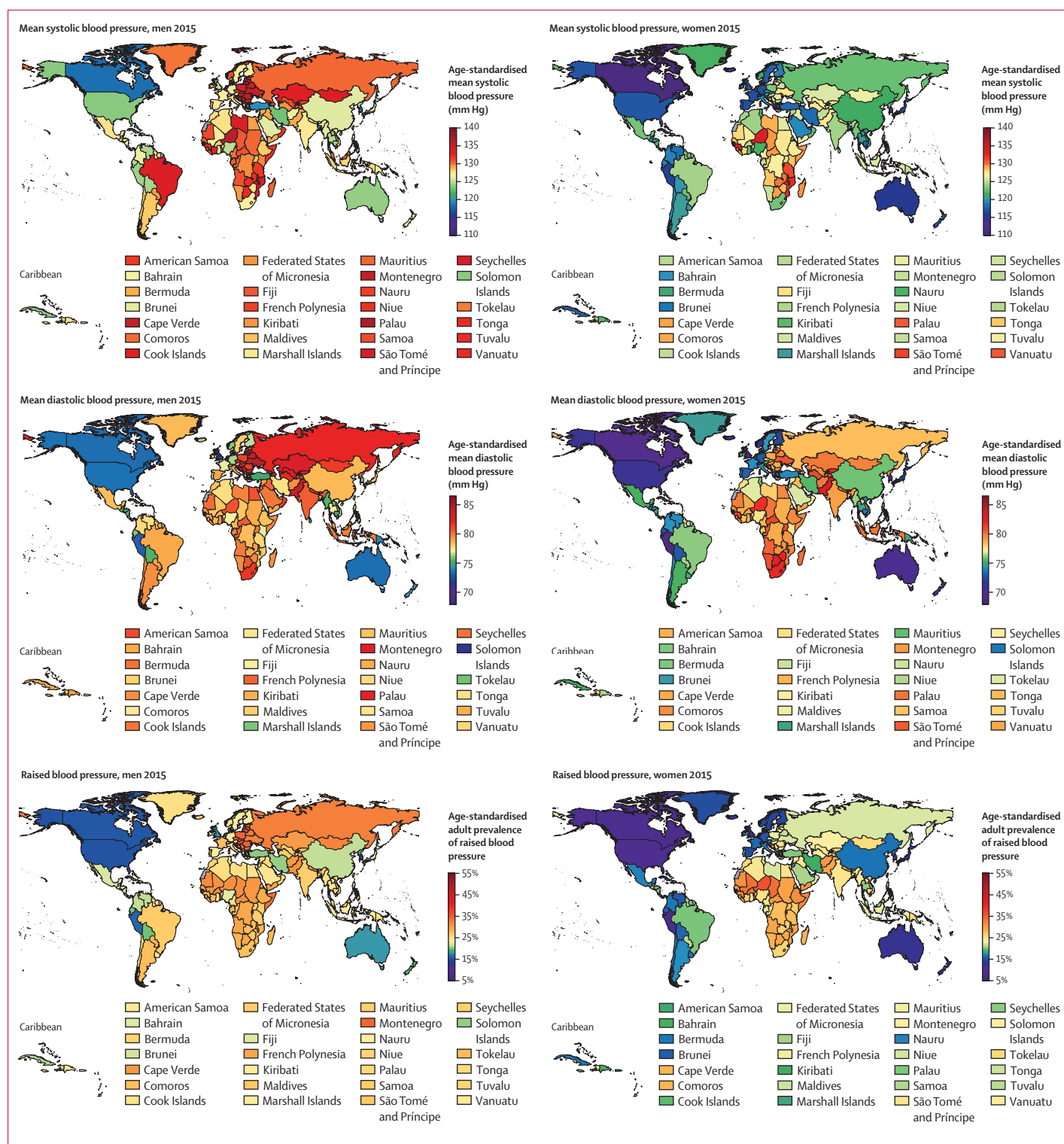


Figure 4: Age-standardised mean systolic blood pressure, mean diastolic blood pressure, and prevalence of raised blood pressure by sex and country in 2015 in people aged 18 years and older. Interactive versions of these maps and downloadable numerical results are available online.

For interactive maps and numerical results see www.ncdrisc.org

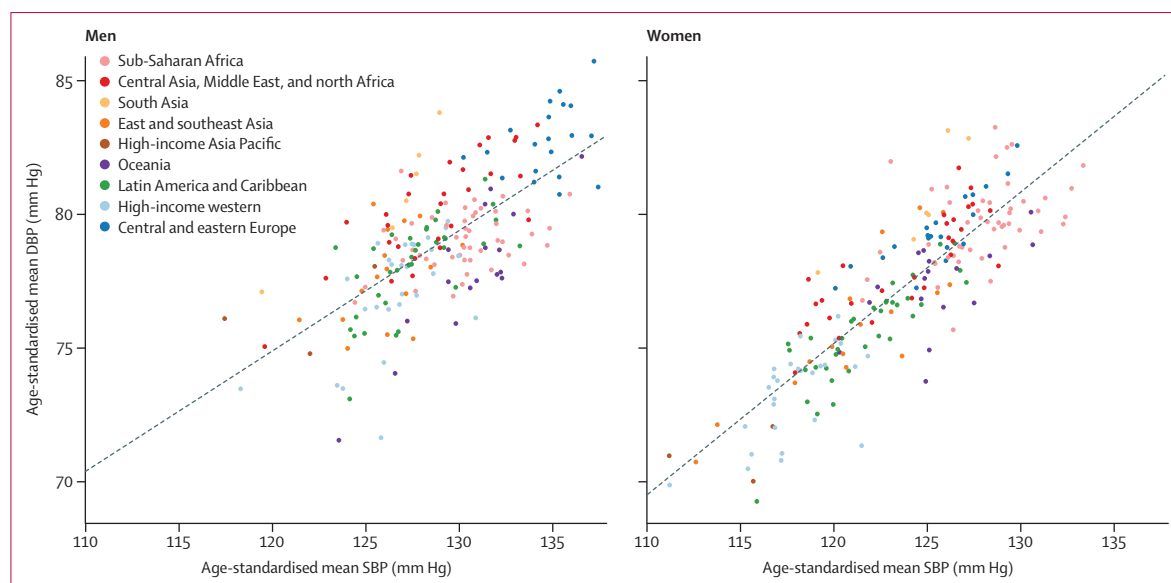


Figure 5: Relation between age-standardised mean systolic and mean diastolic blood pressure in men and women aged 18 years and older in 2015
The dotted line shows the linear association between the two outcomes. DBP=diastolic blood pressure. SBP=systolic blood pressure.

132 mm Hg. Countries with the lowest mean diastolic blood pressure were Peru and several high-income countries including Canada, Australia, the UK, New Zealand, and Singapore. Diastolic blood pressure was high throughout central and eastern Europe, south Asia, and sub-Saharan Africa, with age-standardised mean surpassing 85 mm Hg in Lithuanian men. Mean systolic and mean diastolic blood pressure were correlated across countries (correlation coefficients of 0.69 for men and 0.86 for women in 2015). However, men and women in countries in south Asia, central and eastern Europe, and central Asia, Middle East, and north Africa had higher diastolic blood pressure than expected on the basis of their systolic blood pressure and the systolic blood pressure–diastolic blood pressure association (figure 5); the opposite was seen for men and women in Oceania.

South Korea, Canada, the USA, Peru, the UK, Singapore and Australia had the lowest prevalence of raised blood pressure in 2015 for both sexes, with an age-standardised prevalence of less than 13% in women and less than 19% in men (figure 4). At the other extreme, age-standardised prevalence surpassed 35% in men in some countries in central and eastern Europe including Croatia, Latvia, Lithuania, Hungary, and Slovenia; prevalence was more than 33% in women in a few countries in west Africa.

In 2015, men had higher age-standardised mean systolic blood pressure than women in most countries (figure 6). Men also had higher diastolic blood pressure and prevalence of raised blood pressure than women in most countries, except in sub-Saharan Africa, where the sex pattern was reversed in most countries, and a few countries in Oceania and Asia. The male–female differences in

age-standardised means and prevalence were virtually all due to differences in people younger than 50 years; among people aged 50 years and older, on average men and women had similar mean systolic and diastolic blood pressure and prevalence of raised blood pressure, with countries divided into some with lower and others with higher male blood pressure (results not shown). The male–female difference in blood pressure in 2015 was largest in high-income countries and countries in central and eastern Europe. Compared with 1975, the male excess in mean blood pressure increased in high-income super-regions, central and eastern Europe, Latin America and the Caribbean, and central Asia, Middle East, and north Africa but decreased (and in the case of diastolic blood pressure reversed) in sub-Saharan Africa, Oceania, and south Asia (results not shown).

The estimated number of adults with raised blood pressure increased from 594 million in 1975 to 1.13 billion in 2015 (figure 7), comprising 597 million men and 529 million women. At the global level, this increase was attributable to population growth and ageing, offset partly by falling age-specific prevalence. In the high-income western super-region, the absolute number of people with raised blood pressure has decreased steadily since 1975 because the steep decrease in prevalence outweighed the effect of population growth and ageing. Nonetheless, 141 million adults in the constituent countries had raised blood pressure in 2015. Similarly, in central and eastern Europe, the number of people with raised blood pressure peaked in 1988 and went below its 1975 levels in 2002, driven by decreasing prevalence. In high-income Asia Pacific, the number of people with raised blood pressure has decreased since 2007 but is still higher than it was in 1975. In other

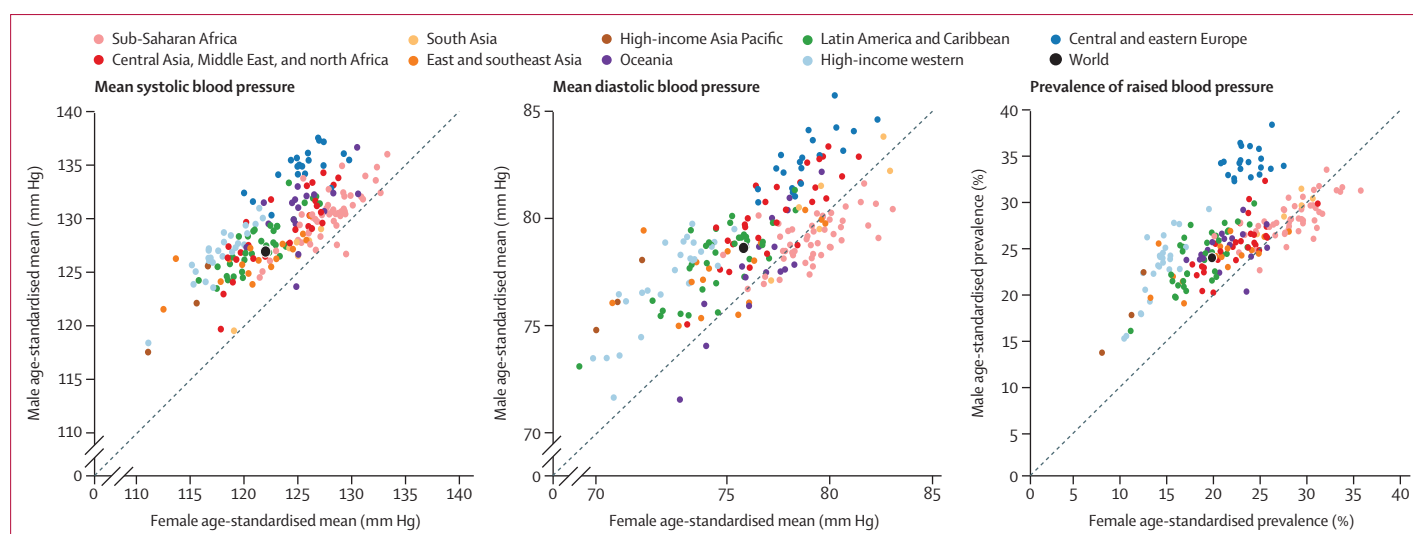


Figure 6: Comparison of age-standardised mean systolic blood pressure, mean diastolic blood pressure, and prevalence of raised blood pressure in men and women aged 18 years and older in 2015

low-income and middle-income super-regions, the number of people with raised blood pressure is still increasing. In Latin America and the Caribbean and central Asia, the Middle East, and north Africa, this rise is a net effect of increase due to population growth and ageing and decrease due to lower age-specific prevalence. In Oceania, south Asia, east and southeast Asia, and sub-Saharan Africa, three quarters or more of the rise is attributable to population growth and ageing, and the remainder is due to an increase in prevalence (figure 7). In 2015, 258 million (23%) of the 1·13 billion adults with raised blood pressure lived in south Asia (199 million of whom in India) and another 235 million (21%) lived in east Asia (226 million of whom in China).

Discussion

Raised blood pressure has transitioned from a risk factor largely affecting high-income countries to one that is now most prevalent in low-income countries in south Asia and sub-Saharan Africa, while being a persistent health issue in central and eastern Europe. Although favourable trends continue in high-income countries, and might also be happening in some middle-income regions, other low-income and middle-income regions are affected by rising, or at best stable but high, blood pressure. The number of people with raised blood pressure in the world has increased by 90% during these four decades, with the majority of the increase occurring in low-income and middle-income countries, and largely driven by the growth and ageing of the population.

At the global level, we estimated lower mean systolic blood pressure in the 1980s, and hence a smaller reduction over time, than reported by Danaei and colleagues,⁵ possibly because we had more data than their earlier analysis. At the regional level, the additional data from low-income and middle-income countries

included in our analysis gave more confidence to our finding of a rise in mean systolic blood pressure in Asia and sub-Saharan Africa than the trends estimated by Danaei and colleagues.⁵ Our results cannot be directly compared with the studies by Kearney and colleagues¹² and Mills and colleagues¹³ because these studies included people who used antihypertensive medicines when calculating prevalence. Despite this difference in the reported metric, the reports are broadly consistent in identifying central and eastern Europe, central Asia, and sub-Saharan Africa as regions at the highest risk. Lawes and colleagues¹⁴ also reported the highest mean systolic blood pressure in central and eastern Europe and central Asia, as we did, but unlike our study they found lower mean systolic blood pressure in south Asia than in most regions. This difference is largely because blood pressure in south Asia has increased since 2000, the reporting year of Lawes and colleagues' study; the difference might also be attributable to us having substantially more data from south Asia than Lawes and colleagues.

The estimated decrease in blood pressure in high-income countries in our analysis is consistent with findings of country studies and the MONICA Project.^{15–34} Fewer studies have analysed blood pressure trends in low-income and middle-income countries than in high-income countries. The available studies suggest reductions in blood pressure in central and possibly eastern Europe,^{35–38} the Middle East and north Africa,³⁹ and Latin America,⁴⁰ and increases in south Asia and sub-Saharan Africa,^{41–43} and possibly in east and southeast Asia.^{44,45}

We also found that the prevalence of raised blood pressure decreased in some regions where mean blood pressure did not change, and remained unchanged where the mean increased. Some other studies^{32,46} have also found a larger decrease in the upper tail of blood

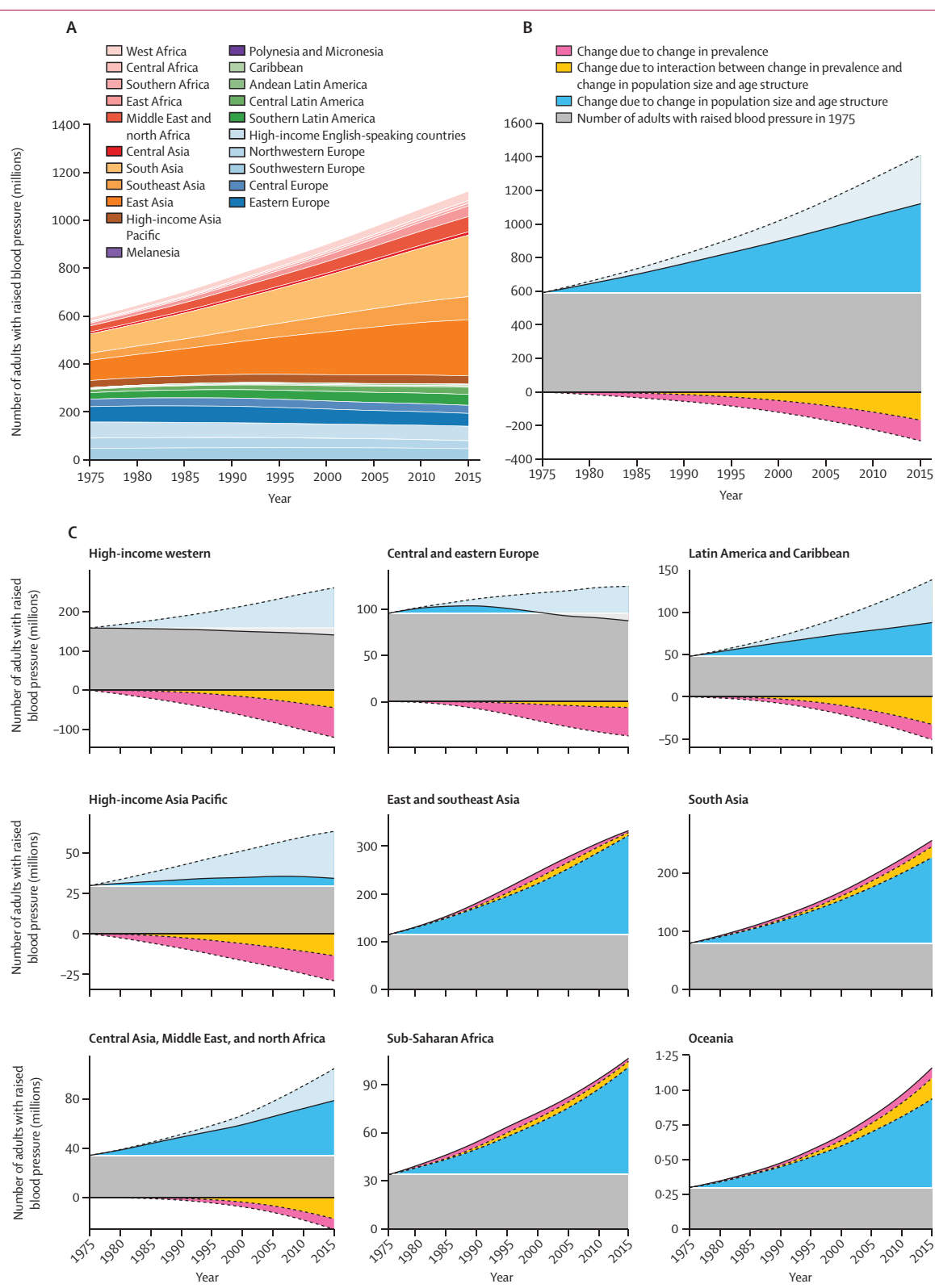


Figure 7: Trends in the number of adults aged 18 years and older with raised blood pressure
Trends are (A) by region; (B) decomposed into the contributions of population growth and ageing, change in prevalence, and interaction of the two for the world; and (C) decomposed into the contributions of population growth and ageing, change in prevalence, and interaction of the two by super-region. (B, C) The solid black lines show the trends in the number of adults with raised blood pressure, and the light blue sections show how much of the rise in numbers due to population growth and ageing has been offset by the decrease in prevalence.

pressure distribution than in its mean. In the MONICA Project,¹⁶ the upper percentiles of blood pressure distribution decreased more than the mean in some communities but not in others. Although the changing shape of the distribution is partly due to antihypertensive drugs, it has also occurred in younger adult ages when medication use is uncommon.^{32,46} To investigate the drivers of the changing distribution would require historical data on multiple determinants of blood pressure throughout the life course. Finally, our finding of a higher mean blood pressure in men than in women, especially in premenopause ages, is consistent with previous studies.⁴⁷

The strengths of our study include its scope in making consistent and comparable estimates of trends in both mean and raised blood pressure over four decades for all the countries in the world. We used a large amount of population-based data covering countries in which more than 97% of the global adult population lives. We used only data from studies that had measured blood pressure to avoid bias in self-reported data. We analysed data according to a consistent protocol, and NCD Risk Factor Collaboration members verified the characteristics of data from each country through repeated checks. We pooled data using a statistical model that took into account the epidemiological features of blood pressure, including non-linear time trends and age associations. Our statistical model used all available data while giving more weight to national data than to subnational and community sources.

Similar to all global analyses, our study is affected by some limitations. First, some countries had no or few data sources, especially those in sub-Saharan Africa and the Caribbean. Estimates for these countries relied mostly or entirely on the statistical model. The absence or scarcity of data is reflected in wider uncertainty intervals of our estimates for these countries and regions, emphasising the importance of national NCD-oriented surveillance. Second, we had fewer data sources for the years before 1990 in most regions, which was reflected in the larger uncertainty for these years. In a sensitivity analysis, we analysed trends starting in 1990 with an identical model, and compared the post-1990 estimates with estimates from the main analysis (which included data from 1975 onwards). The estimates were very similar with correlation coefficients between the estimates from the main and sensitivity analyses being 0.94 or higher in 1990 and 0.98 or higher in 2015 (appendix pp 197, 198). Third, only 53% of sources included people older than 70 years, necessitating the use of data in these older ages elsewhere to infer an age pattern and make estimates in older ages. In view of the ageing trends throughout the world, inclusion of older people in health surveys should be emphasised. Fourth, our model accounted and adjusted for systematic and random errors in subnational and community data. However, the adjustments are not country-specific because estimation of country-specific

adjustments would require national and subnational or community data in the same country and year. Therefore, the correction for each single country remains uncertain. Fifth, although data held by NCD Risk Factor Collaboration members were analysed to provide all the primary outcomes, individual participant data could not be accessed for 20% of data sources. To overcome this issue, we systematically used the reported metrics to estimate all of our primary outcomes; the cross-walking regressions used for this purpose had good predictive accuracy but increased the uncertainty of our estimates. Sixth, over time, standard mercury sphygmomanometers have been replaced by random-zero sphygmomanometers and more recently digital oscillometric devices in health surveys. Similarly, studies differed on whether they used multiple cuff sizes or one cuff size. We note that the effect of measurement device and protocol on population mean and prevalence depends on the circumstances of each survey. For example, an automated digital device with a standard cuff, although not the traditional gold-standard in a clinical setting, avoids observer bias and increases compliance, and possibly even response rate, compared with a standard mercury sphygmomanometer with multiple cuffs.⁴⁸ Nonetheless, measurements from different devices are not fully comparable,^{49–51} which might have affected the estimated trends. When we included device type as study-level covariate in our statistical model, studies using random-zero sphygmomanometers, which were used commonly in the late 1980s and 1990s, had lower mean blood pressure (by about 4.5 mm Hg for systolic blood pressure and by about 3 mm Hg for diastolic blood pressure) and prevalence of raised blood pressure than studies using standard mercury sphygmomanometers. The mean difference between studies using digital devices and mercury sphygmomanometers was about 2 mm Hg for systolic blood pressure and about 0.2 mm Hg for diastolic blood pressure. Finally, blood pressure had been measured only once in some of our data sources. In those sources with multiple measurements, the median difference between the first measurement and the average of subsequent ones was 1.5 mm Hg for systolic blood pressure and 0.0 mm Hg for diastolic blood pressure, suggesting that mean blood pressure and prevalence of raised blood pressure might be slightly overestimated in some of our sources.

Blood pressure is a multifaceted trait, affected by nutrition, environment, and behaviour throughout the life course, including fetal and early childhood nutrition and growth,⁵² adiposity,^{53,54} specific components of diet, especially sodium and potassium intakes,⁵³ alcohol use,^{54,55} smoking,⁵⁶ physical activity,⁵⁴ air pollution,⁵⁷ lead,⁵⁸ noise,⁵⁹ psychosocial stress, and the use of blood pressure lowering drugs. Changes in risk factors and improvements in detection and treatment of raised blood pressure have, at least partly, resulted in the decrease in blood pressure in high-income countries, although the

decrease seems to have begun before or in the absence of specific interventions for risk factors and scale-up of treatment, and is only partly accounted for by the measured risk factors and treatment.^{17,19–21,34,35,46,60–70} In particular, the decrease in high-income and some middle-income countries has happened despite increasing body-mass index.⁷¹

The partly unexplained nature of these favourable trends necessitates speculation about their drivers, which might include unmeasured improvements in early childhood nutrition and year-round availability of fruits and vegetables, which might increase the amount and regularity of their consumption. Our results show that similar decreasing trends in mean blood pressure and prevalence of raised blood pressure might have begun in some middle-income regions, although at a slower rate than trends in high-income regions, but not in the poorest populations, including those in south Asia and sub-Saharan Africa, and in populations affected by major social and economic changes in central and eastern Europe. These populations have low consumption of fresh fruits⁷² and, in many cases, high consumption of salt.⁷³ South Asia and sub-Saharan Africa have the highest prevalence of maternal undernutrition,^{71,74} preterm and small-for-gestational age births, and child undernutrition;^{75,76} they have also had some of the smallest gains in adult height,⁷⁴ which is associated with lower risk of cardiovascular diseases. Many cases of raised blood pressure go untreated in these regions.^{13,77} The absence of these favourable determinants of low blood pressure, coupled with rising body-mass index,⁷¹ might be causing the increase in mean blood pressure in these regions. Therefore, if governments and multinational organisations are to address the large and inequitable burden of cardiovascular diseases and kidney disease associated with high blood pressure, they need to take a multifaceted approach using both population-based strategies throughout the life course and individual lifestyle management and treatment through primary care systems.⁷⁸

Contributors

ME designed the study and oversaw research. Members of the Country and Regional Data Group collected and reanalysed data, and checked pooled data for accuracy of information about their study and other studies in their country. BZ and MDC led data collection. BZ and JB led the statistical analysis. BZ prepared results. Members of the Pooled Analysis and Writing Group collated data, checked all data sources in consultation with the Country and Regional Data Group, analysed pooled data, and prepared results. BZ and ME wrote the first draft of the report with input from other members of the Pooled Analysis and Writing Group. Members of the Country and Regional Data Group commented on the draft report.

NCD Risk Factor Collaboration (NCD-RisC)

Pooled Analysis and Writing (equal contribution)*—Bin Zhou (Imperial College London, UK); James Benthall (Imperial College London, UK)*; Mariachiara Di Cesare (Middlesex University, UK)*; Honor Bixby (Imperial College London, UK); Goodarz Danaei (Harvard T H Chan School of Public Health, USA); Melanie J Cowan (World Health Organization, Switzerland); Christopher J Paciorek (University of California, Berkeley, USA); Gitanjali Singh (Tufts University, USA);

Kaveh Hajifathalian (Harvard T H Chan School of Public Health, USA); James E Bennett (Imperial College London, UK); Cristina Taddei (Imperial College London, UK); Ver Bilano (Imperial College London, UK); Rodrigo M Carrillo-Larco (Universidad Peruana Cayetano Heredia, Peru); Shirin Djalalinia (Tehran University of Medical Sciences, Iran); Shahab Khatibzadeh (Brandeis University, USA); Charles Lugero (Mulago Hospital, Uganda); Niloofar Peykari (Tehran University of Medical Sciences, Iran); Wan Zhu Zhang (Mulago Hospital, Uganda); Yuan Lu (Yale University, USA); Gretchen A Stevens (World Health Organization, Switzerland); Leanne M Riley (World Health Organization, Switzerland); Pascal Bovet (University of Lausanne, Switzerland); Ministry of Health, Seychelles); Prof Paul Elliott (Imperial College London, UK); Prof Dongfeng Gu (National Center for Cardiovascular Diseases, China); Nanyu Ikeda (National Institute of Health and Nutrition, Japan); Prof Rod T Jackson (University of Auckland, New Zealand); Prof Michel Joffres (Simon Fraser University, Canada); Prof Andre Pascal Kengne (South African Medical Research Council, South Africa); Prof Tiina Laatikainen (National Institute for Health and Welfare, Finland); Prof Tai Hing Lam (University of Hong Kong, China); Prof Avula Laxmaiah (National Institute of Nutrition, India); Jing Liu (Capital Medical University Beijing An Zhen Hospital, China); J Jaime Miranda (Universidad Peruana Cayetano Heredia, Peru); Prof Charles K Mondo (Mulago Hospital, Uganda); Hannelore K Neuhauser (Robert Koch Institute, Germany); Prof Johan Sundström (Uppsala University, Sweden); Prof Liam Smeeth (London School of Hygiene & Tropical Medicine, UK); Maroje Sorić (University of Zagreb, Croatia); Prof Mark Woodward (University of Sydney, Australia); University of Oxford, UK); Prof Majid Ezzati (Imperial College London, UK)

Country and Regional Data (equal contribution; listed alphabetically)*—Leandra Abarca-Gómez (Caja Costarricense de Seguro Social, Costa Rica)*; Ziad A Abdeen (Al-Quds University, Palestine)*; Hanan Abdul Rahim (Qatar University, Qatar)*; Niveen M Abu-Rmeileh (Birzeit University, Palestine)*; Benjamin Acosta-Cazares (Instituto Mexicano del Seguro Social, Mexico)*; Robert Adams (The University of Adelaide, Australia)*; Wichai Aekplakorn (Mahidol University, Thailand)*; Kaosar Afsana (BRAC, Bangladesh)*; Carlos A Aguilar-Salinas (Instituto Nacional de Ciencias Médicas y Nutrición, Mexico)*; Charles Agyemang (University of Amsterdam, Netherlands)*; Alireza Ahmadvand (Non-Communicable Diseases Research Center, Iran)*; Wolfgang Ahrens (Leibniz Institute for Prevention Research and Epidemiology—BIPS, Germany)*; Rajaa Al Raddadi (Ministry of Health, Saudi Arabia)*; Rihab Al Woyatan (Ministry of Health, Kuwait)*; Mohamed M Ali (World Health Organization Regional Office for the Eastern Mediterranean, Egypt)*; Ala'a Alkerwi (Luxembourg Institute of Health, Luxembourg)*; Eman Aly (World Health Organization Regional Office for the Eastern Mediterranean, Egypt)*; Philippe Amouyel (Lille University and Hospital, France)*; Antoinette Amuzu (London School of Hygiene & Tropical Medicine, UK)*; Lars Bo Andersen (Sogn and Fjordane University College, Norway)*; Sigmund A Anderssen (Norwegian School of Sport Sciences, Norway)*; Lars Ångquist (Bispebjerg and Frederiksberg Hospitals, Denmark)*; Ranjit Mohan Anjana (Madras Diabetes Research Foundation, India)*; Daniel Ansong (Komfo Anokye Teaching Hospital, Ghana)*; Hajer Aounallah-Skhiri (National Institute of Public Health, Tunisia)*; Joana Araújo (University of Porto, Portugal)*; Inger Ariansen (Norwegian Institute of Public Health, Norway)*; Tahir Aris (Ministry of Health Malaysia, Malaysia)*; Nimmathota Arlappa (National Institute of Nutrition, India)*; Krishna Aryal (Nepal Health Research Council, Nepal)*; Dominique Arveiler (Strasbourg University and Hospital, France)*; Felix K Assah (University of Yaoundé 1, Cameroon)*; Maria Cecilia F Assunção (Federal University of Pelotas, Brazil)*; Mária Avdicová (Regional Authority of Public Health, Banská Bystrica, Slovakia)*; Ana Azevedo (University of Porto Medical School, Portugal)*; Fereidoun Azizi (Shahid Beheshti University of Medical Sciences, Iran)*; Bontha V Babu (Indian Council of Medical Research, India)*; Suhad Bahijri (King Abdulaziz University, Saudi Arabia)*; Nagalla Balakrishna (National Institute of Nutrition, India)*; Piotr Bandosz (Medical University of Gdansk, Poland)*; José R Banegas (Universidad Autónoma de Madrid, Spain)*; Carlo M Barbagallo

(University of Palermo, Italy)*; Alberto Barceló (Pan American Health Organization, USA)*; Amina Barkat (Université Mohammed V de Rabat, Morocco)*; Aluisio J D Barros (Federal University of Pelotas, Brazil)*; Mauro V Barros (University of Pernambuco, Brazil)*; Iqbal Bata (Dalhousie University, Canada)*; Anwar M Batieha (Jordan University of Science and Technology, Jordan)*; Louise A Baur (University of Sydney, Australia)*; Robert Beaglehole (University of Auckland, New Zealand)*; Habiba Ben Romdhane (University Tunis El Manar, Tunisia)*; Mikhail Benet (University Medical Science, Cuba)*; Lowell S Benson (University of Utah School of Medicine, USA)*; Antonio Bernabe-Ortiz (Universidad Peruana Cayetano Heredia, Peru)*; Gailute Bernotiene (Lithuanian University of Health Sciences, Lithuania)*; Heloisa Bettiol (University of São Paulo, Brazil)*; Aroor Bhagyalaxmi (B J Medical College, India)*; Sumit Bharadwaj (Chirayu Medical College, India)*; Santosh K Bhargava (SL Jain Hospital, India)*; Yufang Bi (Shanghai Jiao-Tong University School of Medicine, China)*; Mukharram Bikbov (Ufa Eye Research Institute, Russia)*; Peter Bjerregaard (University of Southern Denmark, Denmark; University of Greenland, Greenland)*; Espen Bjertness (University of Oslo, Norway)*; Cecilia Björkelund (University of Gothenburg, Sweden)*; Anneke Blokstra (National Institute for Public Health and the Environment, Netherlands)*; Simona Bo (University of Turin, Italy)*; Martin Bobak (University College London, UK)*; Heiner Boeing (German Institute of Human Nutrition, Germany)*; Jose G Boggia (Universidad de la República, Uruguay)*; Carlos P Boissonnet (CEMIC, Argentina)*; Vanina Bongard (Toulouse University School of Medicine, France)*; Pascal Bovet (University of Lausanne, Switzerland; Ministry of Health, Seychelles)*; Lutgart Braeckman (Ghent University, Belgium)*; Imperia Brajkovich (Universidad Central de Venezuela, Venezuela)*; Francesco Branca (World Health Organization, Switzerland)*; Juergen Breckenkamp (Bielefeld University, Germany)*; Hermann Brenner (German Cancer Research Center, Germany)*; Lizzy M Brewster (University of Amsterdam, Netherlands)*; Graziella Bruno (University of Turin, Italy)*; H B(as) Bueno-de-Mesquita (National Institute for Public Health and the Environment, Netherlands)*; Anna Bugge (University of Southern Denmark, Denmark)*; Con Burns (Cork Institute of Technology, Ireland)*; Michael Bursztyn (Hadassah-Hebrew University Medical Center, Israel)*; Antonio Cabrera de León (Universidad de La Laguna, Spain)*; Joseph Cacciottolo (University of Malta, Malta)*; Christine Cameron (Canadian Fitness and Lifestyle Research Institute, Canada)*; Günay Can (Istanbul University, Turkey)*; Ana Paula C Cândido (Universidade Federal de Juiz de Fora, Brazil)*; Vincenzo Capuano (Cardiologia di Mercato S Severino, Italy)*; Viviane C Cardoso (University of São Paulo, Brazil)*; Axel C Carlsson (Karolinska Institutet, Sweden)*; Maria J Carvalho (University of Porto, Portugal)*; Felipe F Casanueva (Santiago de Compostela University, Spain)*; Juan-Pablo Casas (University College London, UK)*; Carmelo A Caserta (Associazione Calabrese di Epatologia, Italy)*; Snehalatha Chamukuttan (India Diabetes Research Foundation, India)*; Angelique W Chan (Duke-NUS Medical School, Singapore)*; Queenie Chan (Imperial College London, UK)*; Himanshu K Chaturvedi (National Institute of Medical Statistics, India)*; Nishi Chaturvedi (University College London, UK)*; Chien-Jen Chen (Academia Sinica, Taiwan)*; Fangfang Chen (Capital Institute of Pediatrics, China)*; Huashuai Chen (Duke University, USA)*; Shuohua Chen (Kailuan General Hospital, China)*; Zhengming Chen (University of Oxford, UK)*; Ching-Yu Cheng (Duke-NUS Medical School, Singapore)*; Imane Cherkaoui Dekkaki (Université Mohammed V de Rabat, Morocco)*; Angela Chetrit (The Gertner Institute for Epidemiology and Health Policy Research, Israel)*; Arnaud Chiolerio (Lausanne University Hospital, Switzerland)*; Shu-Ti Chiou (Ministry of Health and Welfare, Taiwan)*; Adela Chirita-Emandi (Victor Babeş University of Medicine and Pharmacy Timisoara, Romania)*; Belong Cho (Seoul National University College of Medicine, South Korea)*; Yumi Cho (Korea Centers for Disease Control and Prevention, South Korea)*; Jerzy Chudek (Medical University of Silesia, Poland)*; Renata Cifkova (Charles University in Prague, Czech Republic)*; Frank Claessens (Katholieke Universiteit Leuven, Belgium)*; Els Clays (Ghent University, Belgium)*; Hans Concin (Agency for Preventive and Social Medicine, Austria)*; Cyrus Cooper (University of Southampton, UK)*; Rachel Cooper (University College London, UK)*; Tara C Coppinger (Cork Institute of Technology, Ireland)*; Simona Costanzo (IRCCS Istituto Neurologico Mediterraneo Neuromed, Italy)*; Dominique Cotel (Institut Pasteur de Lille, France)*; Chris Cowell (Westmead University of Sydney, Australia)*; Cora L Craig (Canadian Fitness and Lifestyle Research Institute, Canada)*; Ana B Crujeiras (CIBEROBN, Spain)*; Juan J Cruz (Universidad Autónoma de Madrid, Spain)*; Graziella D'Arrigo (National Council of Research, Italy)*; Eleonora d'Orsi (Federal University of Santa Catarina, Brazil)*; Jean Dallongeville (Institut Pasteur de Lille, France)*; Albertino Damasceno (Eduardo Mondlane University, Mozambique)*; Goodarz Danaei (Harvard T H Chan School of Public Health, USA)*; Rachel Dankner (The Gertner Institute for Epidemiology and Health Policy Research, Israel)*; Thomas M Dantoft (Research Centre for Prevention and Health, Denmark)*; Luc Dauchet (Lille University Hospital, France)*; Guy De Backer (Ghent University, Belgium)*; Dirk De Bacquer (Ghent University, Belgium)*; Giovanni de Gaetano (IRCCS Istituto Neurologico Mediterraneo Neuromed, Italy)*; Stefaan De Henauw (Ghent University, Belgium)*; Delphine De Smedt (Ghent University, Belgium)*; Mohan Deepa (Madras Diabetes Research Foundation, India)*; Abbas Dehghan (Erasmus Medical Center Rotterdam, Netherlands)*; Hélène Delisle (University of Montreal, Canada)*; Valérie Deschamps (French Public Health Agency, France)*; Klodian Dhana (Erasmus Medical Center Rotterdam, Netherlands)*; Augusto F Di Castelnuovo (IRCCS Istituto Neurologico Mediterraneo Neuromed, Italy)*; Juvenal Soares Dias-da-Costa (Universidade do Vale do Rio dos Sinos, Brazil)*; Alejandro Diaz (National Council of Scientific and Technical Research, Argentina)*; Ty T Dickerson (University of Utah School of Medicine, USA)*; Shirin Djalalinia (Non-Communicable Diseases Research Center, Iran)*; Ha T P Do (National Institute of Nutrition, Vietnam)*; Annette J Dobson (University of Queensland, Australia)*; Chiara Donfrancesco (Istituto Superiore di Sanità, Italy)*; Silvana P Donoso (Universidad de Cuenca, Ecuador)*; Angela Döring (Helmholtz Zentrum München, Germany)*; Kouamelan Doua (Ministère de la Santé et de la Lutte Contre le Sida, Côte d'Ivoire)*; Wojciech Drygas (The Cardinal Wyszyński Institute of Cardiology, Poland)*; Virginija Dulskiene (Lithuanian University of Health Sciences, Lithuania)*; Aleksandar Džakula (University of Zagreb, Croatia)*; Vilnis Dzerve (University of Latvia, Latvia)*; Elzbieta Dzikowska-Zaborszczyk (Medical University of Łódź, Poland)*; Robert Eggertsen (University of Gothenburg, Sweden)*; Ulf Ekelund (Norwegian School of Sport Sciences, Norway)*; Jalila El Ati (National Institute of Nutrition and Food Technology, Tunisia)*; Ute Ellert (Robert Koch Institute, Germany)*; Paul Elliott (Imperial College London, UK)*; Roberto Elosua (Institut Hospital del Mar d'Investigacions Mèdiques, Spain)*; Rajiv T Erasmus (University of Stellenbosch, South Africa)*; Cihangir Erem (Karadeniz Technical University, Turkey)*; Louise Eriksen (University of Southern Denmark, Denmark)*; Jorge Escobedo-de la Peña (Instituto Mexicano del Seguro Social, Mexico)*; Alun Evans (The Queen's University of Belfast, UK)*; David Faeh (University of Zurich, Switzerland)*; Caroline H Fall (University of Southampton, UK)*; Farshad Farzadfar (Tehran University of Medical Sciences, Iran)*; Francisco J Felix-Redondo (Centro de Salud Villanueva Norte, Spain)*; Trevor S Ferguson (The University of the West Indies, Jamaica)*; Daniel Fernández-Bergés (Hospital Don Benito-Villanueva de la Serena, Spain)*; Daniel Ferrante (Ministry of Health, Argentina)*; Marika Ferrari (Council for Agricultural Research and Economics, Italy)*; Catterina Ferreccio (Pontificia Universidad Católica de Chile, Chile)*; Jean Ferrieres (Toulouse University School of Medicine, France)*; Joseph D Finn (University of Manchester, UK)*; Krista Fischer (University of Tartu, Estonia)*; Bernhard Föger (Agency for Preventive and Social Medicine, Austria)*; Leng Huat Foo (Universiti Sains Malaysia, Malaysia)*; Ann-Sofie Forslund (Umeå University, Sweden)*; Maria Forsner (Dalarna University, Sweden)*; Stephen P Fortmann (Stanford University, USA)*; Heba M Fouad (World Health Organization Regional Office for the Eastern Mediterranean, Egypt)*; Damian K Francis (The University of the West Indies, Jamaica)*; Maria do Carmo Franco (Federal University of São Paulo, Brazil)*; Oscar H Franco (Erasmus

- Medical Center Rotterdam, Netherlands)*; Guillermo Frontera (Hospital Universitario Son Espases, Spain)*; Flavio D Fuchs (Hospital de Clinicas de Porto Alegre, Brazil)*; Sandra C Fuchs (Universidade Federal do Rio Grande do Sul, Brazil)*; Yuki Fujita (Kindai University, Japan)*; Takuro Furusawa (Kyoto University, Japan)*; Zbigniew Gaciong (Medical University of Warsaw, Poland)*; Dickman Gareta (University of KwaZulu-Natal, South Africa)*; Sarah P Garnett (University of Sydney, Australia)*; Jean-Michel Gaspoz (Geneva University Hospitals, Switzerland)*; Magda Gasull (CIBER en Epidemiología y Salud Pública, Spain)*; Louise Gates (Australian Bureau of Statistics, Australia)*; Diana Gavrilă (Murcia Regional Health Council, Spain)*; Johanna M Geleijnse (Wageningen University, Netherlands)*; Anoosheh Ghasemian (Endocrinology and Metabolism Research Institute, Iran)*; Anup Ghimire (B P Koirala Institute of Health Sciences, Nepal)*; Simona Giampaoli (Istituto Superiore di Sanità, Italy)*; Francesco Gianfagna (University of Insubria, Italy)*; Jonathan Giovannelli (Lille University Hospital, France)*; Rebecca A Goldsmith (Ministry of Health, Israel)*; Helen Gonçalves (Federal University of Pelotas, Brazil)*; Marcela Gonzalez Gross (Universidad Politécnica de Madrid, Spain)*; Juan P González Rivas (The Andes Clinic of Cardio-Metabolic Studies, Venezuela)*; Frederic Gottrand (Université de Lille 2, France)*; Sidsel Graff-Iversen (Norwegian Institute of Public Health, Norway)*; Dušan Grafnetter (Institute for Clinical and Experimental Medicine, Czech Republic)*; Aneta Grajda (The Children's Memorial Health Institute, Poland)*; Ronald D Gregor (Dalhousie University, Canada)*; Tomasz Grodzicki (Jagiellonian University Medical College, Poland)*; Anders Grøntved (University of Southern Denmark, Denmark)*; Gabriella Gruden (University of Turin, Italy)*; Vera Grujić (University of Novi Sad, Serbia)*; Dongfeng Gu (National Center for Cardiovascular Diseases, China)*; Ong Peng Guan (Singapore Eye Research Institute, Singapore)*; Vilundur Guðnason (University of Iceland, Iceland)*; Ramiro Guerrero (Universidad Icesi, Colombia)*; Idris Guessous (Geneva University Hospitals, Switzerland)*; Andre L Guimaraes (State University of Montes Claros, Brazil)*; Martin C Gulliford (King's College London, UK)*; Johanna Gunnlaugsdóttir (Icelandic Heart Association, Iceland)*; Marc Gunter (Imperial College London, UK)*; Prakash G Gupta (Healis-Sekhsaria Institute for Public Health, India)*; Oye Gureje (University of Ibadan, Nigeria)*; Beata Gurzkowska (The Children's Memorial Health Institute, Poland)*; Laura Gutierrez (Institute for Clinical Effectiveness and Health Policy, Argentina)*; Felix Gutzwiller (University of Zurich, Switzerland)*; Farzad Hadaegh (Shahid Beheshti University of Medical Sciences, Iran)*; Jytte Halkjær (Danish Cancer Society Research Centre, Denmark)*; Ian R Hambleton (The University of the West Indies, Barbados)*; Rebecca Hardy (University College London, UK)*; Rachakulla Harikumar (National Institute of Nutrition, India)*; Jun Hata (Kyushu University, Japan)*; Alison J Hayes (University of Sydney, Australia)*; Jiang He (Tulane University, USA)*; Marleen Elisabeth Hendriks (Academic Medical Center Amsterdam, Netherlands)*; Ana Henriques (University of Porto, Portugal)*; Leticia Hernandez Cadena (National Institute of Public Health, Mexico)*; Herqutanto (Universitas Indonesia, Indonesia)*; Sauli Herrala (Oulu University Hospital, Finland)*; Ramin Heshmat (Chronic Diseases Research Center, Iran)*; Ilpo Tapani Hihtaniemi (Imperial College London, UK)*; Sai Yin Ho (University of Hong Kong, China)*; Suzanne C Ho (The Chinese University of Hong Kong, China)*; Michael Hobbs (University of Western Australia, Australia)*; Albert Hofman (Erasmus Medical Center Rotterdam, Netherlands)*; Gonul Horasan Dinc (Celal Bayar University, Turkey)*; Claudia M Hormiga (Fundación Oftalmológica de Santander, Colombia)*; Bernardo L Horta (Universidade Federal de Pelotas, Brazil)*; Leila Houti (University of Oran 1, Algeria)*; Christina Howitt (The University of the West Indies, Barbados)*; Thein Thein Htay (University of Public Health, Myanmar)*; Aung Soe Htet (Ministry of Health, Myanmar)*; Yonghua Hu (Peking University, China)*; José María Huerta (CIBER en Epidemiología y Salud Pública, Spain)*; Abdullatif S Hussein (Birzeit University, Palestine)*; Inge Huybrechts (International Agency for Research on Cancer, France)*; Nahla Hwalla (American University of Beirut, Lebanon)*; Licia Iacoviello (IRCCS Istituto Neurologico Mediterraneo Neuromed, Italy)*; Anna G Iannone (Cardiologia di Mercato S. Severino, Italy)*; M Mohsen Ibrahim (Cairo University, Egypt)*; Nayu Ikeda (National Institute of Health and Nutrition, Japan)*; M Arfan Ikram (Erasmus Medical Center Rotterdam, Netherlands)*; Vilma E Irazola (Institute for Clinical Effectiveness and Health Policy, Argentina)*; Muhammad Islam (Aga Khan University, Pakistan)*; Vanja Ivkovic (UHC Zagreb, Croatia)*; Masanori Iwasaki (Niigata University, Japan)*; Rod T Jackson (University of Auckland, New Zealand)*; Jeremy M Jacobs (Hadassah University Medical Center, Israel)*; Tazeen Jafar (Duke-NUS Medical School, Singapore)*; Konrad Jamrozik (University of Adelaide, Australia; deceased)*; Imre Janszky (Norwegian University of Science and Technology, Norway)*; Grazyna Jasienska (Jagiellonian University Medical College, Poland)*; Bojan Jelakovic (University of Zagreb School of Medicine, Croatia)*; Chao Qiang Jiang (Guangzhou 12th Hospital, China)*; Michel Joffres (Simon Fraser University, Canada)*; Mattias Johansson (International Agency for Research on Cancer, France)*; Jost B Jonas (Ruprecht-Karls-University of Heidelberg, Germany)*; Torben Jørgensen (Research Centre for Prevention and Health, Denmark)*; Pradeep Joshi (World Health Organization Country Office, India)*; Anne Juolevi (National Institute for Health and Welfare, Finland)*; Gregor Jurak (University of Ljubljana, Slovenia)*; Vesna Jureša (University of Zagreb, Croatia)*; Rudolf Kaaks (German Cancer Research Center, Germany)*; Anthony Kafatos (University of Crete, Greece)*; Ofra Kalter-Leibovici (The Gertner Institute for Epidemiology and Health Policy Research, Israel)*; Nor Azmi Kamaruddin (Universiti Kebangsaan Malaysia, Malaysia)*; Amir Kasaeian (Tehran University of Medical Sciences, Iran)*; Joanne Katz (Johns Hopkins Bloomberg School of Public Health, USA)*; Jussi Kauhanen (University of Eastern Finland, Finland)*; Prabdeep Kaur (National Institute of Epidemiology, India)*; Maryam Kavousi (Erasmus Medical Center Rotterdam, Netherlands)*; Gyulli Kazakbaeva (Ufa Eye Research Institute, Russia)*; Ulrich Keil (University of Münster, Germany)*; Lital Keinan Boker (Israel Center for Disease Control, Israel)*; Sirkka Keinänen-Kiukaanniemi (Oulu University Hospital, Finland)*; Roya Kelishadi (Research Institute for Primordial Prevention of Non-Communicable Disease, Iran)*; Han C G Kemper (VU University Medical Center, Netherlands)*; Andre Pascal Kengne (South African Medical Research Council, South Africa)*; Mathilde Kersting (Research Institute of Child Nutrition, Germany)*; Timothy Key (University of Oxford, UK)*; Yousef Saleh Khader (Jordan University of Science and Technology, Jordan)*; Davood Khalili (Shahid Beheshti University of Medical Sciences, Iran)*; Young-Ho Khang (Seoul National University, South Korea)*; Kay-Tee Khaw (University of Cambridge, UK)*; Stefan Kiechl (Medical University of Innsbruck, Austria)*; Japhet Killewo (Muhimbili University of Health and Allied Sciences, Tanzania)*; Jeongseon Kim (National Cancer Center, South Korea)*; Jurate Klumbiene (Lithuanian University of Health Sciences, Lithuania)*; Elin Kolle (Norwegian School of Sport Sciences, Norway)*; Patrick Kolsteren (Institute of Tropical Medicine, Belgium)*; Paul Korrovits (Tartu University Clinics, Estonia)*; Seppo Koskinen (National Institute for Health and Welfare, Finland)*; Katsuyasu Kouda (Kindai University, Japan)*; Slawomir Koziel (Polish Academy of Sciences Anthropology Unit in Wrocław, Poland)*; Peter Lund Kristensen (University of Southern Denmark, Denmark)*; Steinar Krokstad (Norwegian University of Science and Technology, Norway)*; Daan Kromhout (University of Groningen, Netherlands)*; Herculina S Kruger (North-West University, South Africa)*; Ruzena Kubinova (National Institute of Public Health, Czech Republic)*; Renata Kuciene (Lithuanian University of Health Sciences, Lithuania)*; Diana Kuh (University College London, UK)*; Urho M Kujala (University of Jyväskylä, Finland)*; Krzysztof Kula (Medical University of Łódź, Poland)*; Zbigniew Kulaga (The Children's Memorial Health Institute, Poland)*; R Krishna Kumar (Amrita Institute of Medical Sciences, India)*; Pawel Kurjata (The Cardinal Wyszynski Institute of Cardiology, Poland)*; Yadlapalli S Kusuma (All India Institute of Medical Sciences, India)*; Kari Kuulasmaa (National Institute for Health and Welfare, Finland)*; Catherine Kyobutungi (African Population and Health Research Center, Kenya)*; Tiina Laatikainen (National Institute for Health and Welfare, Finland)*; Carl Lachat (Ghent University, Belgium)*; Tai Hing Lam (University of Hong Kong, China)*; Orlando Landrove (Ministerio de Salud Pública, Cuba)*; Vera Lanska (Institute for Clinical and Experimental Medicine,

Czech Republic)*; Georg Lappas (Sahlgrenska Academy, Sweden)*; Bagher Larijani (Endocrinology and Metabolism Research Center, Iran)*; Lars E Laugsand (Norwegian University of Science and Technology, Norway)*; Avula Laxmaiah (National Institute of Nutrition, India)*; Khanh Le Nguyen Bao (National Institute of Nutrition, Vietnam)*; Tuyen D Le (National Institute of Nutrition, Vietnam)*; Catherine Leclercq (Food and Agriculture Organization, Italy)*; Jeannette Lee (National University of Singapore, Singapore)*; Jeonghee Lee (National Cancer Center, South Korea)*; Terho Lehtimäki (Tampere University Hospital, Finland)*; Rampal Lekhraj (Universiti Putra Malaysia, Malaysia)*; Luz M León-Muñoz (Universidad Autónoma de Madrid, Spain)*; Naomi S Levitt (University of Cape Town, South Africa)*; Yanping Li (Harvard T H Chan School of Public Health, USA)*; Christa L Lilly (West Virginia University, USA)*; Wei-Yen Lim (National University of Singapore, Singapore)*; M Fernanda Lima-Costa (Oswaldo Cruz Foundation Rene Rachou Research Institute, Brazil)*; Hsien-Ho Lin (National Taiwan University, Taiwan)*; Xu Lin (University of Chinese Academy of Sciences, China)*; Allan Linneberg (Research Centre for Prevention and Health, Denmark)*; Lauren Lissner (University of Gothenburg, Sweden)*; Mieczyslaw Litwin (The Children's Memorial Health Institute, Poland)*; Jing Liu (Capital Medical University Beijing An Zhen Hospital, China)*; Roberto Lorbeer (University Medicine Greifswald, Germany)*; Paulo A Lotufo (University of São Paulo, Brazil)*; José Eugenio Lozano (Consejería de Sanidad Junta de Castilla y León, Spain)*; Dalia Luksiene (Lithuanian University of Health Sciences, Lithuania)*; Annamari Lundqvist (National Institute for Health and Welfare, Finland)*; Nuno Lunet (Universidade do Porto, Portugal)*; Per Lytsy (University of Uppsala, Sweden)*; Guansheng Ma (Peking University, China)*; Jun Ma (Peking University, China)*; George L L Machado-Coelho (Universidade Federal de Ouro Preto, Brazil)*; Suka Machi (The Jikei University School of Medicine, Japan)*; Stefania Maggi (National Research Council, Italy)*; Dianna J Magliano (Baker IDI Heart and Diabetes Institute, Australia)*; Marjeta Majer (University of Zagreb, Croatia)*; Marcia Makdisse (Hospital Israelita Albert Einstein, Brazil)*; Reza Malekzadeh (Tehran University of Medical Sciences, Iran)*; Rahul Malhotra (Duke-NUS Medical School, Singapore)*; Kodavanti Mallikharjuna Rao (National Institute of Nutrition, India)*; Sofia Malyutina (Institute of Internal and Preventive Medicine, Russia)*; Yannis Manios (Harokopio University, Greece)*; Jim I Mann (University of Otago, New Zealand)*; Enzo Manzato (University of Padova, Italy)*; Paula Margozzini (Pontificia Universidad Católica de Chile, Chile)*; Pedro Marques-Vidal (Lausanne University Hospital, Switzerland)*; Jaume Marrugat (Institut Hospital del Mar d'Investigacions Mèdiques, Spain)*; Reynaldo Martorell (Emory University, USA)*; Ellisiv B Mathiesen (UiT The Arctic University of Norway, Norway)*; Alicia Matijasevich (University of São Paulo, Brazil)*; 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Vinay B Nangia (Suraj Eye Institute, India)*; Sameer Narake (Healis-Sekhsaria Institute for Public Health, India)*; Eva Maria Navarrete-Muñoz (CIBER en Epidemiología y Salud Pública, Spain)*; Ndeye Coumba Ndiaye (INSERM, France)*; William A Neal (West Virginia University, USA)*; Ilona Nenko (Jagiellonian University Medical College, Poland)*; Flavio Nervi (Pontificia Universidad Católica de Chile, Chile)*; Hannelore K Neuhauser (Robert Koch Institute, Germany)*; Nguyen D Nguyen (The University of Pharmacy and Medicine of Ho Chi Minh City, Vietnam)*; Quang Ngoc Nguyen (Hanoi Medical University, Vietnam)*; Ramfis E Nieto-Martínez (Universidad Centro-Occidental Lisandro Alvarado, Venezuela)*; Teemu J Niiranen (National Institute for Health and Welfare, Finland)*; Guang Ning (Shanghai Jiao-Tong University School of Medicine, China)*; Toshiharu Ninomiya (Kyushu University, Japan)*; Sania Nishtar (Heartfile, Pakistan)*; Marianna Noale (National Research Council, Italy)*; Oscar A Noboa (Universidad de la República, Uruguay)*; Ahmad Ali Noorbala (Tehran University of Medical Sciences, Iran)*; Teresa Norat (Imperial College London, UK)*; Davide Noto (University of Palermo, Italy)*; Mohammad Al Nsour (Eastern Mediterranean Public Health Network, Jordan)*; Dermot O'Reilly (The Queen's University of Belfast, UK)*; Kyungwon Oh (Korea Centers for Disease Control and Prevention, South Korea)*; Maria Teresa A Olinto (Universidade do Vale do Rio dos Sinos, Brazil)*; Isabel O Oliveira (Federal University of Pelotas, Brazil)*; Mohd Azahadi Omar (Ministry of Health Malaysia, Malaysia)*; Altan Onat (Istanbul University, Turkey)*; Pedro Ordunez (Pan American Health Organization, USA)*; Clive Osmond (University of Southampton, UK)*; Sergej M Ostojic (University of Novi Sad, Serbia)*; Johanna A Otero (Fundación Oftalmológica de Santander, Colombia)*; Kim Overvad (Aarhus University, Denmark)*; Ellis Owusu-Dabo (Kwame Nkrumah University of Science and Technology, Ghana)*; Fred Michel Paccaud (Institute for Social and Preventive Medicine, Switzerland)*; Cristina Padez (University of Coimbra, Portugal)*; Elena Pahomova (University of Latvia, Latvia)*; Andrzej Pajak (Jagiellonian University Medical College, Poland)*; Domenico Palli (Cancer Prevention and Research Institute, Italy)*; Luigi Palmieri (Istituto Superiore di Sanità, Italy)*; Songhomitra Panda-Jonas (Ruprecht-Karls-University of Heidelberg, Germany)*; Francesco Panza (University of Bari, Italy)*; Dimitrios Papandreou (Zayed University, UAE)*; Winsome R Parnell (University of Otago, New Zealand)*; Mahboubeh Parsaeian (Tehran University of Medical Sciences, Iran)*; Ivan Pecin (University of Zagreb School of Medicine, Croatia)*; Mangesh S Pednekar (Healis-Sekhsaria Institute for Public Health, India)*; Nasheeta Peer (South African Medical Research Council, South Africa)*; Petra H Peeters (University Medical Center Utrecht, Netherlands)*; Sergio Viana Peixoto (Oswaldo Cruz Foundation Rene Rachou Research Institute, Brazil)*;

- Catherine Pelletier (Public Health Agency of Canada, Canada)*; Markku Peltonen (National Institute for Health and Welfare, Finland)*; Alexandre C Pereira (Heart Institute, Brazil)*; Rosa Marina Pérez (National Institute of Hygiene, Epidemiology and Microbiology, Cuba)*; Annette Peters (Helmholtz Zentrum München, Germany)*; Janina Petkeviciene (Lithuanian University of Health Sciences, Lithuania)*; Niloofar Peykari (Non-Communicable Diseases Research Center, Iran)*; Son Thai Pham (Vietnam National Heart Institute, Vietnam)*; Iris Pigeot (Leibniz Institute for Prevention Research and Epidemiology—BIPS, Germany)*; Hynek Pikhart (University College London, UK)*; Aida Pilav (Federal Ministry of Health, Bosnia and Herzegovina)*; Lorenza Pilotto (Cardiovascular Prevention Centre Udine, Italy)*; Freda Pitakaka (University of New South Wales, Australia)*; Pedro Plans-Rubió (Public Health Agency of Catalonia, Spain)*; Maria Polakowska (The Cardinal Wyszyński Institute of Cardiology, Poland)*; Ozren Polašek (University of Split, Croatia)*; Miquel Porta (Institut Hospital del Mar d'Investigacions Mèdiques, Spain)*; Marileen LP Portegies (Erasmus Medical Center Rotterdam, Netherlands)*; Akram Pourshams (Tehran University of Medical Sciences, Iran)*; Rajendra Pradeepa (Madras Diabetes Research Foundation, India)*; Mathur Prashant (Indian Council of Medical Research, India)*; Jacqueline F Price (University of Edinburgh, UK)*; Maria Puiu (Victor Babeş University of Medicine and Pharmacy Timisoara, Romania)*; Margus Punab (Tartu University Clinics, Estonia)*; Radwan F Qasrawi (Al-Quds University, Palestine)*; Mostafa Qorbani (Alborz University of Medical Sciences, Iran)*; Ivana Radic (University of Novi Sad, Serbia)*; Ricardas Radisauskas (Lithuanian University of Health Sciences, Lithuania)*; Mahfuzar Rahman (BRAC, Bangladesh)*; Olli Raitakari (Turku University Hospital, Finland)*; Manu Raj (Amrita Institute of Medical Sciences, India)*; Sudha Ramachandra Rao (National Institute of Epidemiology, India)*; 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Massimo Salvetti (University of Brescia, Italy)*; Jose Sánchez-Abanto (National Institute of Health, Peru)*; Susana Sans (Catalan Department of Health, Spain)*; Diana Santos (Universidade de Lisboa, Portugal)*; Ina S Santos (Federal University of Pelotas, Brazil)*; Renata Nunes dos Santos (University of Sao Paulo Clinics Hospital, Brazil)*; Rute Santos (University of Porto, Portugal)*; Jouko L Saramies (South Karelia Social and Health Care District, Finland)*; Luis B Sardinha (Universidade de Lisboa, Portugal)*; Giselle Sarganas Margolis (Robert Koch Institut, Germany)*; Nizar Sarrafzadegan (Isfahan Cardiovascular Research Center, Iran)*; Kai-Uwe Saum (German Cancer Research Center, Germany)*; Savvas C Savva (Research and Education Institute of Child Health, Cyprus)*; Marcia Scazufca (University of Sao Paulo Clinics Hospital, Brazil)*; Herman Schargrodsky (Hospital Italiano de Buenos Aires, Argentina)*; Ione J Schneider (Federal University of Santa Catarina, Brazil)*; Constance Schultsz (Academic Medical Center Amsterdam, Netherlands)*; Aletta E Schutte (South African Medical Research Council, South Africa; North-West University, South Africa)*; Abhijit Sen (Norwegian University of Science and Technology, Norway)*; Idowu O Senbanjo (Lagos State University College of Medicine, Nigeria)*; Sadaf G Sepanlou (Digestive Diseases Research Institute, Iran)*; Sanjib K Sharma (B P Koirala Institute of Health Sciences, Nepal)*; Jonathan E Shaw (Baker IDI Heart and Diabetes Institute, Australia)*; Kenji Shibuya (The University of Tokyo, Japan)*; Dong Wook Shin (Seoul National University College of Medicine, South Korea)*; Youchan Shin (Singapore Eye Research Institute, Singapore)*; Rosalynn Siantar (Singapore Eye Research Institute, Singapore)*; Abba M Sibai (American University of Beirut, Lebanon)*; Diego Augusto Santos Silva (Federal University of Santa Catarina, Brazil)*; Mary Simon (India Diabetes Research Foundation, India)*; Judith Simons (St Vincent's Hospital, Australia)*; Leon A Simons (University of New South Wales, Australia)*; Michael Sjöström (Karolinska Institutet, Sweden)*; Sine Skovbjerg (Research Centre for Prevention and Health, Denmark)*; Jolanta Slowikowska-Hilczner (Medical University of Łódź, Poland)*; Przemysław Słusarczyk (International Institute of Molecular and Cell Biology, Poland)*; Liam Smeeth (London School of Hygiene & Tropical Medicine, UK)*; Margaret C Smith (University of Oxford, UK)*; Marieke B Snijder (Academic Medical Center Amsterdam, Netherlands)*; Hung-Kwan So (The Chinese University of Hong Kong, China)*; Eugène Sobngwi (University of Yaoundé 1, Cameroon)*; Stefan Söderberg (Umeå University, Sweden)*; Vincenzo Solfrizzi (University of Bari, Italy)*; Emily Sonestedt (Lund University, Sweden)*; Yi Song (Peking University, China)*; Thorkild IA Sørensen (University of Copenhagen, Denmark)*; Maroje Soric (University of Zagreb, Croatia)*; Charles Sossa Jérôme (Institut Régional de Santé Publique, Benin)*; Aicha Soumare (University of Bordeaux, France)*; Jan A Staessen (University of Leuven, Belgium)*; Gregor Starc (University of Ljubljana, Slovenia)*; Maria G Stathopoulou (INSERM, France)*; Bill Stavreski (Heart Foundation, Australia)*; Jostein Steene-Johannessen (Norwegian School of Sport Sciences, Norway)*; Peter Stehle (Bonn University, Germany)*; Aryeh D Stein (Emory University, USA)*; George S Stergiou (Sotiria Hospital, Greece)*; Jochanan Stessman (Hadassah University Medical Center, Israel)*; Jutta Stieber (Helmholtz Zentrum München, Germany)*; Doris Stöckl (Helmholtz Zentrum München, Germany)*; Tanja Stocks (Lund University, Sweden)*; Jakub Stokwiszewski (National Institute of Public Health-National Institute of Hygiene, Poland)*; Karien Stronks (University of Amsterdam, Netherlands)*; Maria Wany Strufaldi (Federal University of São Paulo, Brazil)*; Chien-An Sun (Fu Jen Catholic University, Taiwan)*; Johan Sundström (Uppsala University, Sweden)*; Yn-Tz Sung (The Chinese University of Hong Kong, China)*; Paibul Suriyawongpaisal (Mahidol University, Thailand)*; Rody G Sy (University of the Philippines, Philippines)*; E Shyong Tai (National University of Singapore, Singapore)*; Mari-Liis Tammeosoo (University of Tartu, Estonia)*; Abdonas Tamosiunas (Lithuanian University of Health Sciences, Lithuania)*; Line Tang (Research Centre for Prevention and Health, Denmark)*; Xun Tang (Peking University, China)*; Frank Tanser (University of KwaZulu-Natal, South Africa)*; Yong Tao (Peking University, China)*; Mohammed Rasoul Tarawneh (Ministry of Health, Jordan)*; Carolina B Tarqui-Mamani (National Institute of Health, Peru)*; Anne Taylor (The University of Adelaide, Australia)*; Holger Theobald (Karolinska Institutet, Sweden)*; Lutgarde Thijs (University of Leuven, Belgium)*; Betina H Thuesen (Research Centre for Prevention and Health, Denmark)*; Anne Tjønneland (Danish Cancer Society Research Centre, Denmark)*; Hanna K Tolonen (National Institute for Health and Welfare, Finland)*; Janne S Tolstrup (University of Southern Denmark, Denmark)*; Murat Topbas (Karadeniz Technical University, Turkey)*; Roman Topór-Madry (Jagiellonian University Medical College, Poland)*;

María José Tormo (Murcia Regional Health Council, Spain)*; Maties Torrent (IB-SALUT Area de Salut de Menorca, Spain)*; Pierre Traissac (Institut de Recherche pour le Développement, France)*; Dimitrios Trichopoulos (Harvard T H Chan School of Public Health, USA, deceased)*; Antonia Trichopoulou (Hellenic Health Foundation, Greece)*; Oanh T H Trinh (The University of Pharmacy and Medicine of Ho Chi Minh City, Vietnam)*; Atul Trivedi (Government Medical College, India)*; Lechaba Tshepo (Sefako Makgatho Health Science University, South Africa)*; Marshall K Tulloch-Reid (The University of the West Indies, Jamaica)*; Tomi-Pekka Tuomainen (University of Eastern Finland, Finland)*; Jaakko Tuomilehto (Dasman Diabetes Institute, Kuwait)*; Maria L Turley (Ministry of Health, New Zealand)*; Per Tynelius (Karolinska Institutet, Sweden)*; Christophe Tzourio (University of Bordeaux, France)*; Peter Ueda (Harvard T H Chan School of Public Health, USA)*; Eunice Ugel (Universidad Centro-Occidental Lisandro Alvarado, Venezuela)*; Hanno Ulmer (Medical University of Innsbruck, Austria)*; Hannu M T Uusitalo (University of Tampere Tays Eye Center, Finland)*; Gonzalo Valdivia (Pontificia Universidad Católica de Chile, Chile)*; Damaskini Valvi (Harvard T H Chan School of Public Health, USA)*; Yvonne T van der Schouw (University Medical Center Utrecht, Netherlands)*; Koen Van Herck (Ghent University, Belgium)*; Lenie van Rossem (University Medical Center Utrecht, Netherlands)*; Irene GM van Valkengoed (Academic Medical Center Amsterdam, Netherlands)*; Dirk Vanderschueren (Katholieke Universiteit Leuven, Belgium)*; Diego Vanuzzo (Centro di Prevenzione Cardiovascolare Udine, Italy)*; Lars Vatten (Norwegian University of Science and Technology, Norway)*; Tomas Vega (Consejería de Sanidad Junta de Castilla y León, Spain)*; Gustavo Velasquez-Melendez (Universidade Federal de Minas Gerais, Brazil)*; Giovanni Veronesi (University of Insubria, Italy)*; W M Monique Verschuren (National Institute for Public Health and the Environment, Netherlands)*; Roosmarijn Verstraeten (Institute of Tropical Medicine, Belgium)*; Cesar G Vitoria (Universidade Federal de Pelotas, Brazil)*; Lucie Viet (National Institute for Public Health and the Environment, Netherlands)*; Eira Viikari-Juntura (Finnish Institute of Occupational Health, Finland)*; Paolo Vineis (Imperial College London, UK)*; Jesus Vioque (Universidad Miguel Hernandez, Spain)*; Jyrki K Virtanen (University of Eastern Finland, Finland)*; Sophie Visvikis-Siest (INSERM, France)*; Bharathi Viswanathan (Ministry of Health, Seychelles)*; Peter Vollenweider (Lausanne University Hospital, Switzerland)*; Sari Voutilainen (University of Eastern Finland, Finland)*; Ana Vrdoljak (UHC Zagreb, Croatia)*; Martine Vrijheid (Centre for Research in Environmental Epidemiology, Spain)*; Alisha N Wade (University of the Witwatersrand, South Africa)*; Aline Wagner (University of Strasbourg, France)*; Janette Walton (University College Cork, Ireland)*; Wan Nazaimoon Wan Mohamad (Institute for Medical Research, Malaysia)*; Ming-Dong Wang (Public Health Agency of Canada, Canada)*; Qian Wang (Xinjiang Medical University, China)*; Ya Xing Wang (Beijing Tongren Hospital, China)*; S Goya Wannamethee (University College London, UK)*; Nicholas Wareham (University of Cambridge, UK)*; Niels Wederhopp (University of Southern Denmark, Denmark)*; Deepa Weerasekera (Ministry of Health, New Zealand)*; Peter H Whincup (St George's, University of London, UK)*; Kurt Widhalm (Medical University of Vienna, Austria)*; Indah S Widyahening (Universitas Indonesia, Indonesia)*; Andrzej Wiecek (Medical University of Silesia, Poland)*; Alet H Wijga (National Institute for Public Health and the Environment, Netherlands)*; Rainford J Wilks (The University of the West Indies, Jamaica)*; Johann Willeit (Medical University of Innsbruck, Austria)*; Peter Willeit (Medical University of Innsbruck, Austria)*; Emmanuel A Williams (Komfo Anokye Teaching Hospital, Ghana)*; Tom Wilsaard (UiT The Arctic University of Norway, Norway)*; Bogdan Wojtyniak (National Institute of Public Health-National Institute of Hygiene, Poland)*; Tien Yin Wong (Duke-NUS Medical School, Singapore)*; Roy A Wong-McClure (Caja Costarricense de Seguro Social, Costa Rica)*; Jean Woo (The Chinese University of Hong Kong, China)*; Mark Woodward (University of Sydney, Australia); University of Oxford, UK)*; Aleksander Giwercman Wu (Lund University, Sweden)*; Frederick C Wau (University of Manchester, UK)*; Shou Ling Wu (Kailuan General Hospital, China)*; Haiquan Xu

(Institute of Food and Nutrition Development of Ministry of Agriculture, China)*; Weili Yan (Children's Hospital of Fudan University, China)*; Xiaoguang Yang (Chinese Center for Disease Control and Prevention, China)*; Xingwang Ye (University of Chinese Academy of Sciences, China)*; Panayiotis K Yiallourous (University of Cyprus, Cyprus)*; Akihiro Yoshihara (Niigata University, Japan)*; Novie O Younger-Coleman (The University of the West Indies, Jamaica)*; Ahmad F Yusoff (Ministry of Health, Malaysia)*; Muhammad Fadhli M Yusoff (Institute of Public Health, Malaysia)*; Sabina Zambon (University of Padova, Italy)*; Tomasz Zdrojewski (Medical University of Gdansk, Poland)*; Yi Zeng (Duke University, USA); Peking University, China)*; Dong Zhao (Capital Medical University Beijing An Zhen Hospital, China)*; Wenhua Zhao (Chinese Center for Disease Control and Prevention, China)*; Yingfeng Zheng (Singapore Eye Research Institute, Singapore)*; Dan Zhu (Inner Mongolia Medical University, China)*; Esther Zimmermann (Bispebjerg and Frederiksberg Hospitals, Denmark)*; Julio Zuñiga Cisneros (Gorgas Memorial Institute of Public Health, Panama)*

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